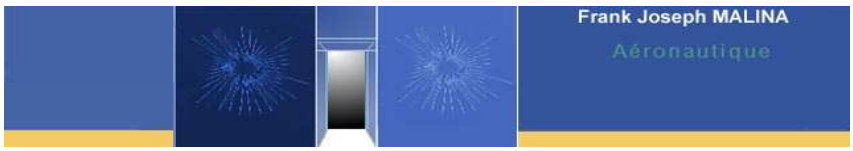

Evolution of Asphalt Rocket Propellants From World War II Jpl/Aerojet Research To Postwar Spin-Offs by The Rocket Research Institute

by Charles J. Piper III, George S. James, Frank H. Winter, and John Bluth - 9/3/2006

I - INTRODUCTION

This paper traces the evolution of asphalt-based solid propellant rocket motors and their production techniques from their beginnings in the early 1940s at the GALCIT project of the California Institute of Technology; through the production by Aerojet during World War II of thousands of Jet Assisted Take-Off (JATO) units for assisting heavily-loaded aircraft into the air; and to the post-war evolution of these asphalt-base propellant rocket motors by the Rocket Research Institute, (RRI), into high thrust, short duration, propulsion systems for launching educational payloads to multi-mile altitudes at the RRI's Federally approved sites. The emphasis on the RRI's propellant development background and the research requirements that lead to the creation of a family of high thrust asphalt-perchlorate rocket motors has necessitated deferring to future papers the RRI research leading to high performance solid propellant nozzeless rocket motors and also the development of "at-launch-site" propellant manufacturing and loading systems, a necessity so as to remain in compliance with Federal and State requirements for transportation of solid propellant rocket motor within the U.S.

II – THE GALCIT RESEARCH PROJECT

October 31, l936 was an important date in establishing a tradition in the United States of universities and institutions encouraging educator supervised student experimental rocketry. On that date, in the Arroyo Seco river bed, near Pasadena, California, Rudolph Schott, Apollo M.O. Smith, Frank J. Malina, Edward S. Forman, and John W. Parsons, students and co-workers from the Guggenheim Aeronautical Laboratory, California Institute of Technology (GALCIT), under the leadership of Frank J. Malina, with the encouragement of Dr. Theodore von Karman, statically tested their first rocket thrust chamber burning gaseous oxygen and methyl alcohol **(Ref.1)**.

Dr. von Karman's sanctioning of this experimental program allowed Malina and the other Caltech engineering students to use some of the Lab's facilities to conduct a study on both liquid and solid propellant rockets toward the design of a high-altitude sounding rocket, though no monies were available for experimental apparatus from the GALCIT's budget. The Caltech student project also included theoretical analyses on solid propellant end-burning grain characteristics. The work would go toward completing Malina's, and other student's master degrees **(Refs. 2 & 3)**.

Among other students participating in the project were William Bollay and Hue shen Tsien, Also two individuals, who were not Caltech students, were permitted to participate in the Project, namely John W. Parsons and Edward S. Forman **(Refs. 4 & 5).** Parsons and Forman had been conducting their own solid propellant rocket experiments and wished to build a liquid propellant system but lacked the technical resources and therefore turned to GALCIT **(Ref. 6).** In time, the work attracted the attention of newspapers and popular scientific journals **(Refs. 7-10)**. An unexpected event during these early years was the visit of Dr. Robert Goddard during the summer of 1936 to Dr. Robert A. Millikan at Caltech. Dr, Millikan was a member of a committee appointed by the Daniel and Florence Guggenheim Foundation to advise on the support given by the foundation to Goddard for the development of a sounding rocket.

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Malina's discussions with Dr. Goddard about the GALCIT student group lead to Malina's subsequent visit to the Goddard facility in Roswell, New Mexico **(Refs. 11-13).**

The initial gaseous oxygen and methyl alcohol test lead to the creation of the GALCIT Rocket Research Project in l937 **(Refs. 14-17).**

By December 1938, the Committee on Army Air Corps Research of the National Academy of Sciences invited Malina to come to Washington to give expert information on the potentials of rocketry. General Henry A. Arnold, Commander, Army Air Corps, had asked the Academy to seek advice on rockets as assisted take-off of heavily loaded aircraft. This resulted in Malina's "Report on Jet Propulsion for the National Academy of Sciences Committee on Air Corps Research" of 21 December 1938 and the Academy's grant of $1,000 for a study of assisted take-off with rockets **(Ref. 18).**

However, research by author Winter has shown that this concept was not new, since H.H. Bales patented rocket assisted take-off (ATO) of airplanes as early as 1910, while in 1929, a Junkers J-33 seaplane fitted with ATO was successfully tested at Dessau, Germany. These efforts may have been unknown to Arnold and the Academy but the various well-publicized rocket-propelled

glider flights of Fritz von Opel and others from 1928-1931 probably were known, although the rocket units for these earliest ATO efforts used black powder a low specific impulse solid propellant **(Ref. 19).**

According to Malina, the word "rocket" was "still in such bad repute in 'serious' scientific circles," that he and von Karman chose the alternate word, "jet," or "jet propulsion," which later would appear as part of Aerojet's name.

Malina went on to say, "Incidentally, when Caltech obtained this first government grant for rocket research, Jerome C. Hunsaker of the Massachusetts Institute of Technology agreed to study for the Air Corps the de-icing problem of windshields, then serious aircraft problem, and told von Karman: "You can have the Buck Roger's job" **(Refs.20 & 21).**

On 1 July 1939, a $10,000 contract was signed in which the GALCIT Project became the Air Corps Jet Propulsion Research Project (ACJP) to study and experiment on Jet-Assisted-Take-Off (ATO or JATO), as well as the application of rockets for the "super-performance" of aircraft. In the latter application, rockets were to be an auxiliary power plant of the aircraft for increasing its performance in flight, not only take-offs. Von Kármán was head of the new project while Malina, Parsons, and Forman formed the nucleus of its staff. Work was continued with both solid and liquid propellant motors **(Ref. 22).**

Prior to World War II, composite solid propellants, from the 19th Century Congreve war rockets even to the initial work of the GALCIT group, 130 years later, often exhibited relatively short storage life times prior to use, due to the compressed propellant cracking from temperature changes **(Refs. 23 & 24).**

Hundreds of tests were made with different powder mixtures before the first solid propellant rocket motor was successfully developed. It was a 28-lb thrust/12 second duration unit containing two pounds of an ammonium nitrate based propellant called GALCIT 27. The propellant was pressed into the combustion chamber, which had a blotting paper liner, in 32 separate increments by a plunger with a conical nose shape at a pressure of 18 tons per square inch **(Ref. 25)**.

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Use of these small rocket motors culminated in the first successful U.S. solid-propellant JATO flight test, on 16 August 1941, and the first American manned flight of an aircraft propelled by rocket thrust alone, on 23 August 1941. In these flights, the JATOs were mounted, three under each wing of an Ercoupe monoplane piloted by Army Air Corps Captain Homer A. Boushey, Jr., at March Field, California **(Refs. 26-28)**.

It was most fortunate that the flight tests were carried out close to the location of the project, which permitted the rocket motors to e fired within a few days from the time they were loaded with propellant. Following the flight tests, it was found that after the motors were exposed to simulated storage and temperature conditions over several days they exploded in most cases. But the Navy Department regarded the successful Ercoupe tests with much interest from the point of view of application of rockets from the assisted take-off of aircraft from aircraft carriers. Upon the urging of Lt. C. F. Fischer of the Bureau of Aeronautics, who had witnessed the tests, a contract was placed by the Navy with the Project in early 1942 for the development of a 200 lb. 8 second unit **(Ref. 29).** Malina noted that when the Project had initiated work on rocket engines for the "superperformance" of aircraft in 1939, it was not evident whether either a solid or liquid propellant type could be constructed to meet service requirements. "Therefore we investigated both" **(Ref. 30).**

In September 1941, barely weeks after the Ercoupe flights, the ACJP Project completed tests on a red fuming nitric acid In (RFNA) and gasoline rocket motor with 500-pounds thrust. Von Kármán then recommended to the Air Material Command (AMC) that future liquid JATO flight tests be carried out. For instance, one thousand pound-thrust motors could be placed in the nacelles of a Douglas A-20A twin-engine bomber.

Also, during September 1941, Robert Goddard began work on liquid propellant (liquid oxygen/gasoline) JATO under contract to the Navy and the Army Air Corps, delivering a device to both agencies on September 1942 **(Refs. 31 & 32).**

The viability of von Karman's recommendation for storable liquid propellant JATO systems was shown the following spring on April 15, 1942, when the GALCIT Project outfitted an A-20A with liquid JATOS and it became the first aircraft in the United States to have liquid rocket assistance in taking off when it was flown by Major Paul H. Dane at Muroc Air Base, California, in the Mojave Desert, north of Pasadena **(Ref. 33).**

III – CREATION OF AEROJET AND SUBSEQUENT JOINT RESEARCH WITH JPL

It became evident in 1941, following the successful flight tests of the Ercoupe and with good progress being made in the development of a liquid propellant JATO, that steps would soon have to be taken for the production of JATOs for the Air Force and the Navy. Various existing aircraft companies in Southern California were approached by von Karman to set up a special rocket engine division. However none of the aircraft industry leaders saw a future for rocket propulsion. Consequently, after the counsel of Andrew G. Haley, von Karman's attorney, and a favorable discussions of the idea with General Franklin O. Carroll, chief of Wright Field Experimental Engineering Section, and Colonel Shaw, who advised von Kármán and the other members of the ACJP Project to form their own company, the Aerojet Engineering Corporation, now the Aerojet-General Corporation, was organized at the end of 1941 and formally incorporated on March 19, 1942 **(Refs.34 & 35).**

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Nevertheless, it was one thing to start the Aerojet Engineering Corporation; it was another to

overcome the known technical problems in the corporation's sole product, the amide pressed propellant JATOs that tended to explode unexpectedly after a period of storage. GALCIT 27 had serious problems during temperature changes. It was found that one of the ingredients in GALCIT 27, ammonium nitrate, has a peculiar temperature property. At 87 degrees F., it undergoes a crystalline phase change. Years later, this problem was solved by adding certain ingredients that inhibited this phenomenon.

However, at the time the use of ammonium nitrate, as an oxidizer, in solid propellants for rockets (at least at JPL) was essentially abandoned **(Ref. 36).**

For Parsons, the spring of 1942 was one of desperation in trying to find a solid propellant that could be stored without later exploding. However, in June 1942 Parsons suggested trying a radical new propellant. It would consist of potassium perchlorate as an oxidizer and paving asphalt as a fuel-binder. After being mixed, the chemicals would be heated and then cast in the combustion chamber. This formula was called GALCIT 53. A test of the propellant, designated GACCIT 53, was quickly made and the results were so promising that work on other propellant types was dropped for a long time. Parsons was assisted in this development of the asphalt base propellant by Mark Mills and Fred Miller **(Ref. 37-39).** This meant they invented a castable, case-bonded composite propellant charge

That this was a joint discovery by Parsons and Fred Miller is supported by Parsons and Fred Miller applying together for a propellant patent in 1943 for a castable asphalt-perchlorate formula; it was granted in 1951 (2,563,265) in Parsons' name only and his rights assigned to the Aerojet Corporation. No evidence shows Parsons consulting any outsiders to help him solve his spring

1941 JATO problems. Although in 1932 Ed Forman and Parsons had made a solid fuel rocket conceptually similar, using aluminum and wax composite as the fuel **(Ref 40).**

Author James recalls, during 1945, when he was working at the 10-foot GALCIT Wind Tunnel on the Caltech campus, that the small library within the building contained the three volumes of Military Pyrotechnics by Henry Faber, which had been published by the Government Printing Office during World War I.

In Volume 2 was described the manufacturing process for a smoke producing torch using 29 percent of Barrett-specification pitch as one ingredient. After the pitch was melted in a steam-jacketed kettle it was mixed with the other ingredients to produce the smoke torch. Parsons certainly had access to this small library during the late 1930's while the rocket research project was on campus. Possibly, having read of this process, which successfully used pitch in a pyrotechnic composition, gave Parsons the confirmation he needed to suggest pitch as a castable propellant for the early JATOs.

Subsequently, years later in 1977, at the IAA History Symposium in Stockholm, author James heard Homer Boushey Jr., the pilot of the Ercoupe, remembering the spring of 1942 and the story that he had heard about the Parsons' breakthrough: "After watching a roofing crew apply hot tar, [Parsons] conceived the idea of mixing the black powder and potassium perchlorate with a flexible, rubber-like substance so cracks and voids would not form" **(Ref 41)**.

The Navy contract for 100 JATO units delivering 200 lb. thrust for 8 seconds was successfully completed with GALCIT 53 as the propellant **(Ref. 42).** The initial asphalt base formulation, GALCIT 53 was superceded in 1943 by GALCIT 61-C, which was the basis for JATOs that

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boosted thousands of aircraft during World War II **(Ref. 43).**

GALCIT 61-C consisted of 76% potassium perchlorate and 24% fuel. The fuel component was 70% Texaco No. 18 asphalt and 30% Union Oil Company Pure Penn SAE No. 10 lubricating oil. The fuel was liquefied at about 275degrees F, the pulverized potassium perchlorate added to it, and the mixture thoroughly stirred. The mixture was then poured into the combustion chamber, which had been previously lined with a material similar to the fuel component, and allowed to cool and become hard. This propellant when burned at a chamber pressure of 2,000 psi had a chamber temperature of 3,000-3,500 degrees F, a specific impulse of 186, and an exhaust velocity of about 5,900 ft. per second. Storage temperature limits were from -9 degrees F to +120 degrees F **(Ref. 44).**

By the spring of 1943 the Army Air Corps no longer ordered JATOs; bulldozers could make longer airstrips more quickly and cheaply than airplanes could be modified to carry JATOs. However, by this time Navy aircraft carriers were becoming the main strike force against Japan in the Pacific and they needed takeoff assistance by rockets.

Fritz Zwicky, Aerojet's chief of research and development starting in the late summer or early fall of 1943, described Aerojet during this time from his point of view as follows:[i] Aerojet had continuing problems during late 1942 and early 1943 as the larger thrust JATOs continued to explode. Fifteen percent of the JATOs tested on a baby aircraft carrier docked at San Diego blew apart **(Ref. 45).** The Navy wanted to cancel its contract with Aerojet but Zwicky convinced the Navy JATO people at Annapolis to give Aerojet $300,000 more for JATOs **(Ref. 46).**

Bill Gore, an early employee and later a vice-president of Aerojet, said he trusted his company's work so implicitly that he would take off with a JATO under his arm. He flew JATO tests on PBY's at Patuxant as a Marine pilot and also piloted a plane with Aerojet JATOS at Cedar Point, Maryland on March 5, 1943 **(Ref. 47)**.

Calvin Bolster and James Russell, former students of von Kaman's, asked for a Navy demonstration on the East Coast in August 1943 of solid propellant JATOs. Jack Parsons supervised a smoky lift off of a Grumman plane using JATOS on the aircraft carrier Charger at Norfolk, Virginia. The Navy told him to come back when Aerojet had developed a propellant with less smoke. This prompted the eventual development of "Aeroplex," a low smoke propellant, initially used on an experimental basis. However, despite the smoky exhaust from these asphalt base JATOS, the Navy began placing large orders for 200-lb as well as 500- and 1000-lb motors.

The first Aerojet solid propellant JATO purchased and used operationally by the Navy was the 12-AS-1000, which was static-fired on a PBM (No. 48212) in July 1944, at Annapolis. The first combat consignment amounted to 30 of the motors, which were later used at Iwo Jima. Additional squadrons were soon equipped with them for use on PBM and PB 2Y aircraft. It was felt, justifiably at the time, that liquid propellant JATOs were still experimental, more expensive, unpredictable, and required greater training time than solid propellant types pioneered by Aerojet. These factors explain the early success of the solid JATOs, leading to the Navy's massive order of 40,000 12-AS-1000 units in late 1944 **(Ref. 48).**

With the development of solid propellant JATOs in hand, the Aerojet Corporation turned at the same time to producing many copies of a workable liquid propellant JATO. On August 12, 1942, Aerojet started work under Aerojet Work Order 1 on copies of the A-20a motor. These motors were called AL-1000, a code-type of designation meaning "Aerojet-liquid-1000 pound thrust" or

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8AS-1000 meant eight seconds burn, Aerojet, solid, 1000 pounds thrust. Sixty-two A-20A units were planned.

The first Aerojet offices were at 3330 East Colorado Boulevard in Pasadena, with 15 employees. They were moved on October 7, 1942 to 285 West Colorado Boulevard to a Hudson automobile salesroom and occupied 36,000 square feet of space. A rocket production facility for the liquid propellant A-20 units was set up in the automobile repair room.

To make the solid propellant Army Air Corps JATOs (one hundred X8AS-200), Aerojet rented space from the Day and Night Water Heater Manufacturing Company that was making flare bombs at their plant in Azusa, California in January 1943, with testing facilities established in a nearby unused gravel pit.

The site occupied 48 acres; by June 1943 it had 22 buildings. Called the Propellant Plant and Proving Grounds, it had a propellant loading facility (32 buildings and 65 employees in May 1944), "Gulch facilities" for solid and liquid research (21 buildings in May 1944) and static firing stands (about 15 associated structures in May 1944).

As 1943 ended a Navy contract for 2000 JATO units was uncompleted by Thanksgiving. Office personnel from 285 W. Colorado worked a day at their desks and then drove to Azusa for a night shift of making JATOS. Fred Miller had to certify each motor upon completion. He worked around the clock and slept on a cot. Work was completed with a government inspector's leniency on January 1, 1944.

During the war years Aerojet maintained close ties with JPL, particularly in the testing of products and sharing of research developments. As an example, Aerojet and JPL jointly worked on eliminating the problem of smoke (and hydrochloric acid) from ammonium perchlorate-based propellants. This close relationship continued until later in 1944 when General Tire Corporation

would gain majority control of the stock of Aerojet. However, this purchased allowed a line of credit from a Pasadena bank making it possible to produce 800 JATO units a month and again when the Navy demanded an increase in Aerojet's JATO production from 800 to 20,000 units a month.

During the fall of 1944 Aerojet supplied 30AS-1000C motors (which burned GALCIT 61C) for JPL's Private A. Aerojet also supplied these same motors for JPL's Private F in the spring of 1945.

JATOs are credited during and after the war with numerous heroic rescues. One such rescue was when an Air Force C-47 equipped with skis and JATOs saved a dozen downed pilots stranded on an icecap in Greenland in 1949. During the war, JATOs are said to have saved an estimated 4,500 men. Little wonder some 200,000 of Aerojet's 14AS-1000, known affectionately as "the old Smoky," were produced.

In 1945 Charles E. Bartley, under the JPL-ORDCIT Project adapted Thiokol's castable polysulfide rubber as a fuel for these solid rocket motors **(Ref.49)**. This development of room temperature castable propellants eventually became the basis for most large-scale solid propellant rocket motors

Author James spent the summer of 1946, at the invitation of Frank Malina, as an assistant test pit mechanic in one of the liquid rocket test bays at the Jet Propulsion Laboratory. Most of his duties were concerned with static firing tests of liquid monopropellant nitromethane rocket thrust chambers. However, he also spend several weeks as a test pit mechanic at the solid rocket propellant test bay in which Charles Bartley and his staff were testing these first room temperature

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castable solid propellants made from Thiokol liquid polymer. James well remembers the initial air bubble entrapment problems, which caused erratic burning in the experimental rocket motors using

these composite solid propellants under the joint GALCIT and Aerojet research program.

Subsequently, vacuum casting of the propellant solved this problem.

The 14-AS-1000, Mk2, Mod 3 JATO came into wide civilian use after World War II and on September 13, 1946 was the first JATO approved by the Civil Aeronautics Administration, (Engine Type Certificate No. 249) for use on the Douglas DC-3 and DC-4 aircraft. (This was later extended to the DC-6 and Convair 240.) Thus, in the following year an American Airlines DC-4 inaugurated the commercial use of JATO in its non-stop flight from Mexico City to Philadelphia, the JATOs permitting the addition of five tons to its payload. South and Central American airlines found JATOs invaluable for boosting heavily laden cargo and passenger planes from short airstrips hacked out of jungles and from mountainous strips where air-breathing airplane engines often found it difficult to "breath" during take-offs **(Ref. 50).**

With the introduction of the big jet carriers and other jet craft with afterburner capability, and consequent increased length of runways, JATOs became superfluous and Aerojet's production of them (carried out at its Sacramento, California, plant from the Korean War) greatly diminished.

However, the evolution of the polysulfide castable propellants from 1945 inevitably saw Aerojet's solid rocket motors make quantum leaps in size and performance. Aerojet-General Corporation continued to grow as the United States' need for military rockets increased during the Cold War.

During the latter part of 1967, at the request of Aerojet Vice President, Bill Gore, author James, then employed by the Aerojet Liquid Rocket Plant, located and arranged the acquisition of 14 early Aerojet solid and liquid rocket systems. Subsequently, on March 6, 1968, these historic rocket propulsion systems were donated by Aerojet to the Smithsonian Institution's National Air and Space Museum. Included in the collection were one of Fred Miller's original Ercoupe 28 lb thrust motors and a 14-AS-1000, Mk2, Mod 3, JATO **(Ref. 51).**

The following October 31, 1968, thirty-two years after the first static test firing in the Arroyo Seco, five of the original GALCIT team, Frank J. Malina, William A. Bollay, Edward S. Forman, Apollo M.O. Smith and William C. Rockefeller were honored by a ceremony at JPL by the placement of a historic bronze marker on JPL property, approximately 400 yards from the original site of the first test on October 31, 1936.

JPL Director Dr. William H. Pickering and Caltech President Dr. Lee A. DuBridge, who presided over the ceremony, stated that: "The students cited in bronze studied at the Guggenheim Aeronautical Laboratory of the California Institute of Technology (GALCIT) and were encouraged in their experimentation by the GALCIT director, the late Dr. Theodore von Karman. With the test firing of the rocket engine 32 years ago, Caltech became the first American university to actively sponsor rocket research. The work soon gained government sponsorship and eventually----in 1944---led to the establishment of the Jet Propulsion Laboratory" **(Refs. 52-53)**.

IV –FOUNDING OF THE ROCKET RESEARCH INSTITUTE

The Rocket Research Institute, Inc., (RRI), celebrates the 56th Anniversary of its founding this year. Since 1943 the RRI has evolved into the non-profit consulting organization of engineering, education, and safety professionals who volunteer their free time and services to participate in and guide the Institute's research programs; space education and experiential science motivation projects; rocket safety consulting activities; workshops and seminars **(Refs 54-56).**

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Late, in 1942, author James read the book, ***Rockets Through Space***, written in 1936 by P. E.

Cleator, which was the only book in the Glendale public library on astronautics that James's father

could find for his son's science project **(Ref. 57)**.

The forecasts of future travel by rocket colorfully depicted in the Sunday newspaper comic strip "Buck Rogers in the 25th Century, **(Refs. 58-61)** suddenly were brought back to the 20th Century byMr. Cleator's 1936 accounts of research by rocket pioneers, Robert H. Goddard, Robert Esnault-Peltier, and Hermann Oberth, as well as the interplanetary societies they inspired, the German Rocket Society, the British Interplanetary Society, and the American Rocket Society **(Refs. 62-63)**.

Thus, on January 6, 1943, author James, inspired by Cleator's accounts of 2oth Century rocket research founded the nucleus, of the present Rocket Research Institute, Inc., under the name of Southern California Rocket Society (SCRS) along with five other ninth grade Clark Junior High School students, John Cipperly, Jim and George Fox, Jim Hess, and Charles Payne, at in La Crescenta, California **(Refs. 64-67).** The first "adult supervisor" of the SCRS was James's father, Serge V. James.

With its youthfully enthusiastic goals of rocket safety and space education, the SCRS became the Glendale Rocket Society (1943-1946); then the Reaction Research Society (1946-1949); and since 1949, the Rocket Research Institute, a name that defines the educational and engineering nature of this of this non-profit corporation. Since 1968 the Institute has been an Institutional Member of the International Astronautical Federation, the world's leading non-governmental space organization.

The RRI, has been involved in supervised experiential programs for students and adults since 1943; when the world's largest rocket propulsion system was the yet generally unknown V-2; to today, where now, in addition to the launches of student payloads by supervised experimental organizations such as the RRI, student experiments are also launched on occasion by industrial and governmental unmanned launch vehicles as well as on NASA Space Shuttle launches, which often carry student experiments as part of their payloads **(Refs. 68-88).**

Safety is always the principal concern in all Institute activities. The RRI firmly believes that programs in educational supervised experimental rocketry can be undertaken only if the three factors of competent guidance, professionally designed equipment, and proper safety facilities are available. The Institute addresses the safety and educational needs of space science "hands-on" experiential programs by also maintaining static and flight test facilities. For over 50 years, such facilities have proven to be "tools" for effectively nurturing the creativity of aerospace professionals through the experience of working avocationally at such sites "to develop their ideas." Also they have served as positive extracurricular sources of motivation for young people involved in science and engineering courses, as well as for their teachers **(Refs. 89-96).** .

In addition, the RRI's National Rocket Safety Registry (NRSR) program, for young people, is a free consulting service, initiated in 1957, for student space science education and safe supervised rocketry projects from primary through university levels. The NRSR program is conducted in cooperation with industry, government agencies, educators, and parents **(Ref. 97).**

V –INITIAL RRI SOLID PROPELLANT RESEARCH

Much of the material in Section V and it's subsections, is presented as background to illustrate the truly evolutionary nature of the research programs within the Institute. In addition to the RRI's financial resources, research depends principally upon the available voluntary spare time of staff members in regard to their responsibilities in their professional vocations. Thus, sometimes,

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research projects, as described in this paper may take years to bring to fruition.

One of the first projects of the young organization in 1943 was the design of a mail-carrying rocket. In reading ***Rockets Through Space***, the group had been particularly intrigued with the mail-rocket research of a young Austrian engineer, Friedrich Schmied (1902-1994).

On February 2, 1931, Mr. Schmiedl had launched the first "public" demonstration of rocket mail

from the Schoekel mountain plateau in Steirmark, Austria, to the town of Radegund with his "V-7"

rocket that carried 102 covers and cards. This demonstration helped increase public awareness, at a time long before intercontinental ballistic missiles, of a peaceful vision of the future with large cargo carrying rockets. This experiment also raised funds for his research program, which continued until Austria was annexed by Germany in 1938 **(Refs. 98-101).** Particularly ofinterest to our group was the possibility of raising funds for our research through flying special rocket mail covers for collectors.

Virtually 50 years later, on October 17, 1993, author James and IAA History Committee associates, Herve Moulin, Karlheinz Rohrwild, Elmar Wild, Frank Winter, and Konrad Dannenberg, had the extraordinary opportunity to meet Mr. Schmiedl at his home in Graz to compare notes and learn of his life-long efforts to promote the peaceful uses of rocket propulsion, **(Ref. 102)**,

V.a. Black Powder Research

Going back to 1943, the RRI member's first choice for propelling our mail rocket design was to develop a black-powder rocket motor for propulsion, as did Mr. Schmiedl in 1931.

In the case of the young organization, it took a little over a year to produce a successful small-scale black powder propulsion system. The March-April, 1944, issue of the *Glendale Rocket Society Bulletin* proclaimed in large letters on the cover, "Society Models Will Fly' and went on to describe the 200-foot high by 1000-foot long flight trajectory of a l-inch diameter by 5-inch long black powder rocket constructed by Bert Anderson and his father **(Refs. 103-104).** This event initiated the Institute's training device research and its rocket safety publications. .

The success of this project had been aided during the previous months of static testing and attempted launches by the purchase of the best pyrotechnics manufacturing books of the day, *The Chemistry of Powder and Explosives* by Tenny L. Davis and *Pyrotechnics*, by George W. Weingart **(Refs. 105-106).** The subsequent donation of several 8-pound skyrocket charges to the RRI research program by the California Rocket Society (CRS) resolved any problems with producing reliable paper-cased black powder propulsion systems. The 8-pound charges were spares from the CRS 1941 flight tests at the same Arroyo Seco site used in 1936 by Frank Malina's group and earlier in 1917 by Dr. Goddard **(Refs. 107-110.),**

Author James recalls that, because of war-time military security, he and his young associates had no idea of the truly significant rocket propulsion research was being conducted at the GALCIT Project in southern California less than 15 miles from where the RRI was formed. "We certainly could not know of the years of trials with pressed composite propellants that Frank Malina and his associates had encountered prior to their successful development of a castable solid propellant, as noted earlier in this paper."

The group's small scale black powder rocket motor success, as noted in the local press, prompted other youngsters to try, on their own, to duplicate the RRI's research. Unfortunately, in some cases, the efforts of these other students to short-cut the laborious process of making the necessary heavy

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walled paper tubing by using metal tubing resulted in explosions.

The reporting, in the newspapers, of a number of such accidents, prompted author James, in 1948 to compile *Model Rockets, Rocket Building for Modelers,* the first of the RRI's continuing series of rocket d safety guides. **(Refs 111-115).** This first manual was based on the results of experiments, begun in 1944, involving safe model rocket aircraft and small rocket flight vehicles. The

experimenters, whose work was represented, included Bert Anderson, Carroll Evans, John S. James, Bob Ray, Lee Rosenthal Rodney Skager, Dick Schenz, and author James **(Ref.116).**

It may well be that the present term "Model Rocket" was inspired by this initial safety guide. One of the purchasers of a 1950 edition of *Model Rockets* was Orville Carlisle. Mr. Carlisle later developed and patented the concept of a small black powder propelled flight vehicle, using a motor similar to that described in *Model Rockets*, which ejected a small parachute at the apex of its flight. He called his unit the Rock-A-Chute. As G. Harry Stine, the initial popularizer of model rocketry, described in his 1976 memoir paper at the SYRE session at the 27 IAF Congress, that he and Mr. Carlisle learned of each other in 1957. Subsequently, they enlisting the pyrotechnic skills of Vern Estes, founder of Estes Industries, who developed in 1959 a fully automatic model rocket motor manufacturing machine. This removed the last technical obstacle from producing high quality reliable model rocket motors, for today's space science motivation programs for young people**(Ref. 117).** From 1965 to 1971 over 7,000 model rockets were launched under RRI supervision at the PRSTC by hundreds of students and their parents as well as teachers without a single injury - a truly remarkable safety record, **(Ref. 118)**.

As many of the cold-war related solid propellant formulations became unclassified some commercial model rocket motor manufacturers expanded their production to include higher impulse motors, now called High Power Model Rocket Motors. The controlled availability of these commercially prepared motors is the most recent category of professionally prepared rocket propulsion systems to be adapted to educational programs in the United States. Among the advocates of applying these motors to both sport and educational model rocketry has been the Tripoli Rocketry Association.

These non-metallic-cased propulsion systems range in total impulse from the 0.9-lb/sec of the E units to the 288-lb/sec of the J series motors. Building and launching large lightweight, non-metallic, flight vehicles that use these motors is now a hobby for hundreds of adults.

For special demonstrations, RRI Rocketpost flights 89/43 through 94/46 have used these motors for experiments in circumstances that precluded using more powerful propulsion systems **(Ref. 119).**

V.b. The Evolution of Micrograin Solid Propellant Rocket Motors

Christmas vacation from Clark Junior High School, 1942/1943, was particularly significant for the RRI's propellant and cargo (mail rocket) future. Author James's friend, John Cipperly had received a Gilbert Chemistry set for Christmas. As he and James tried various formulations, they came upon a rapidly burning mixture using two of the ingredients from the four-ingredient green flare formulation. Paper tubes filled with what became named "Micrograin," because of its dust-like nature, upon ignition, would with a flash propel themselves from one end of John's yard to the other.

However, at the time this low cost, rapid burning, propellant was discovered the advantages of what had formulated was not realized and the researchers returned to trying to develop black powder rockets because of a misconception--- "The models using this powder were more projectiles than

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rockets since a 'true' rocket develops its speed gradually instead of all at once as in the Micrograin models," **(Ref. 120)**.

By 1945, with information in newspapers on the use by WWII's Allied troops,of the bazooka with it's extremely short duration firing rocket motor, the young researchers realized the error of their

"all at once" definition. Consequently, the group again took up Micrograin rocket motor development.

With the end of World War II, a vast variety of surplus materials became available including

aluminum tubing in all diameters. Thus, in 1946, Bob Ray, an imaginative RRI member, following his original work with paper-tubed Micrograin rockets, began a series of experiments using aluminum tubing. Sometimes the rockets would work well and sometimes they would stagger upward, burning slowly, and melting the aluminum tubing.

Author James believed that the problem was due to the Micrograin propellant packing from its own weight in the long aluminum tubing and causing irregular combustion. He conceived the first of the "capsule" systems to prevent the propellant from packing **(Ref 121)**, The specific impulse of the dust-like Micrograin propellant is less than 50, at the relatively low chamber pressure that test results found most successful. Consequently, the evolution of the capsule concept continued over the next decade, with contributions by Dennis Scharosch, and Ruth Harper

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By May, 1946, research on the Micrograin propellant rocket had definitely shown that if an initial mail rocket were to be built it would use this type of solid propellant motor instead of the black powder type, originally called for in the 1943 designs. Consequently, research was accelerated to develop a Micrograin cargo (rocketpost) carrying flight system.

On February 23, 1947, Submiler, a seven-foot long, two-inch diameter, Micrograin rocket, weighing 16.5-lb, with a three-foot long propellant chamber was launched at the RRI Palmdale, California, flight range and traveled a distance of 2,100 feet **(Ref. 122).**

A month later, on March 23, 1947, Miler 1, a fifteen foot long, two and three quarters inch diameter rocket, weighing 54.25-lb, with a ten-foot long propellant chamber, containing 27-lb of Micrograin, traveled a distance of 3,500 feet at the RRI Palmdale site **(Ref. 123).**

On June 1, 1947, Miler II, similar to Miler 1, but launched at a 60-degree angle traveled over 4,000 feet in distance **(Ref. 124).** This confirmed that the design was sufficient for the group's first rocket-mail experiment, Rocketpost 47/1, from Winterhaven, California, across the Colorado River, to Yuma, Arizona.

On June 28, 1947, at Winterhaven, Rocket 1, after being on the launch rack in the over 120 degree temperature so the RKO-Pathe news photographers could photograph it, upon launch, exploded half way in its trajectory across the Colorado River. The waterproof mail compartment landed in the river and floated downstream. Unfortunately, the U.S. Border Station personnel would not allow the team to go into Mexico because of problems with the local Indians. Thus, the 300 special covers continued downstream to the Gulf of Mexico and never were recovered Rocket 2, stored in the shade, made a perfect flight of over 5,000 feet to conclude the first California to Arizona rocket mail flight **(Refs.125 & 126)**

The development of cargo rockets continued at the Palmdale test site. On October 26, 1947, R4EX73, a ten-foot long modified Yuma-type Micrograin rocket, carrying parachute releases and

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other mechanisms, was launched vertically and rose to an altitude of 5600 feet **(Refs.127 & 128).** The previous record altitude of 3,300 feet for non-governmental or foundation supported rocket research had been set in 1931 by the Verein fur Raumschiffart, a German rocket society, no longer in existence, **(Ref. 129)**. Naturally, the members were aware of their American hero, Dr. Robert Goddard's, liquid rocket flight to 7,500 feet in 1936, but rationalized that his research, unlike that

of the young researchers, was sponsored **(Ref. 130)**.

Armed with the success of the October launching, and with the continued need for research funds, Rocketpost experiment 48/2 was conducted with eight cargo rockets, on March 28, 1948, at Searles

Dry Lake, near Trona, California **(Refs.131 & 132)**. An important design change was that these rockets, rather than carrying the special covers forward of the rocket motor carried the covers in special compartments built into the rocket fins. Seven of the eight rockets made perfect flights. However, rocket number seven exploded shortly after leaving the launching rack. Its cargo of 600 envelopes in the fins was undamaged. Inspection of the rocket afterwards revealed that part of the propellant support system had not burned and clogged the nozzle,

Two years later, for Rocketpost 50/3, on January 28, 1950, all four cargo rockets, fitted with an improved propellant support system, flew perfectly at the Searles Dry Lake launch site **(Refs. 133 & 134)**.

Since 1950, to the date of this presentation in 1999, 71 of the RRI's long, slender, 3-inch diameter, standard Micrograin cargo rockets, with motor lengths ranging from 12-feet to 14-feet, have carried over 66,000 special commemorative envelopes and AstroNotes in 33 of the Institute's fund-raising rocketpost demonstrations without any motor related problems **(Ref. 135).**

Rocket motors, using Micrograin in loose form, depending on motor configuration, have demonstrated burning rates ranging from 60 to well over 200 inches per second. The propellant provides a reliable low cost system and, with its low combustion pressure, produces a high degree of safety. Total impulse for these Micrograin cargo rocket motors averages 1400 lb-sec.

Because of its low specific impulse the principal use of Micrograin has been for initial RRI student flight training vehicles such as the GODDARD II. In 1957, Albert Files, a high school student in Sacramento and a member of the RRI sponsored Sacramento Rocketeers, developed the GODDARD I as a basic student training rocket for NRSR programs, prior to the availability of what has come to be know as model rocket motors. He named it in honor of the American Rocket Pioneer**(Ref. 136)**. This relatively simple, 3-ft long by 1-in, Micrograin rocket was based upon the initial RRI research by Bob Ray in 1946... It is made from inexpensive materials and is capable of rising to altitudes of between 1000-ft to 2000-ft, at supervised student launchings such as those conducted at the RRI Carson City and Smoke Creek Flight Ranges, north of Reno, Nevada **(Ref. 137)**.

In 1966, author Piper pioneered the development of an all fiberglass five-foot long Goddard II Standard Micrograin Rocket capable of reaching altitudes in excess of 7,000 feet carrying parachute recovery mechanisms **(Ref. 138)**..

Perhaps the largest Micrograin system flown to date using the most recent version of the propellant suspension system was the 14-ft long by 4-inch diameter rocket motor, constructed by David Ruzzo of Sunnyvale, California, under the guidance of Ruth Harper, which contained 150-lb of Micrograin propellant. On May 30, 1983, it was successfully launched on a several mile flight at Smoke Creek '83, the annual Institute rocket safety field trip **(Ref. 139).**

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Information on Micrograin formulation spread to Europe early in the 1950s and it has propelled literally thousands of student rocket vehicles all over the world. As papers at the annual Supervision of Youth Research Experiments (SYRE) sessions during the International Astronautical Federation (IAF) Congresses have indicated, characteristics of the propellant were

still actively being studied by students and researchers in the 1980's in static test and flight programs not only in the United States but also in Belgium, the Netherlands, Sweden, and the former Yugoslavia, **(Ref. 140)**.

V.c. Initial RRI Asphalt –Perchlorate Rocket Motor Systems

With the end of World War II, in August 1945. among the wartime technology declassified was that for the asphalt-perchlorate propellant, GALCIT 61C. Earlier, in June, 1945, author James was able to obtain a job at the GALCIT l0-Foot Wind Tunnel at the California Institute of Technology campus in Pasadena, California,, through the help of his Explorer Scoutmaster, Mr. Robert Wise, who worked there. Thus, author James had an opportunity to meet Dr. Theodore von Karman who introduced him to Dr. Frank Malina and to Dr.Hsue-Shen Tsien.

Dr. Hsue-Shen-Tsien was a brilliant member of Dr. von Karman's team. He unfortunately was deported to China during the Senator McCarthy era inspite of appeals from many leaders of the American aerospace industry. The loss to the future of U.S. space efforts was a plus to the Chinese space program, which he subsequently founded at the request of the Chinese Government **(Refs 141-143).**

In the fall of 1945, James's job became an evening part-time one, while he attended Glendale College. One evening in the spring of 1946, Dr. Hsue-Shen Tsien mentioned, when author James was at work, that the JPL wartime book *Jet Propulsion* had been declassified and some copies were available at the Caltech bookstore **(Ref.144).** . A copy was quickly purchased and put on the RRI office bookshelf.

Subsequently, author James spent the summer of 1946, at the invitation of Frank Malina, as an assistant Test Pit Mechanic at the Jet Propulsion Laboratory. Most of his duties were concerned with tests of the monopropellant Nitromethane. However, he did spend several weeks as a test pit mechanic at the solid propellant test bay in which there were being tested the first room temperature castable solid propellants made from Thiokol liquid polymer. As was noted earlier in this paper, development of propellants using these polymers, in time, completely changed solid propellant rocketry.

Using the information in *Jet Propulsion*, Russell Sessing and author James began the development of small, asphalt-perchlorate based, 100-pound thrust, 10-second duration copper nozzled rocket motors late in 1948. By 1949. these RRI "mini-JATOs," were firing successfully in static tests on weekends at the Institute's Mint Canyon static test site, near Saugus, California.

The successful first flight test, with the mini-JATO as the second stage occurred on July 2, 1949, following many successful static tests. "The Micrograin booster for this two-stage combination was a 2-foot section of 2 1/2 inch diameter stainless steel tubing. It was attached to the restricted burning rocket by means of a 9-inch long section of 2-1/2 inch diameter aluminum tubing which fit into the retainer ring of the restricted rocket nozzle. Since ignition of the restricted rocket was uncertain, it was to be ignited first and then the booster. This necessitated tying the two rockets together with a cord that was to be burned when the booster fired. The rocket was fitted with four 5-inch wide by 8-inch long aluminum fins.

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"On the fourth attempt the restricted rocket ignited and broke the cord attaching it to the Micrograin booster. As it left the rack, it started to veer, at this time the booster fired. The booster passed by the veering second stage rocket, barely missing it. The restricted rocket continued veering and described an arc until it attained enough velocity to promote stable flight. The rocket began straight-line flight at an angle of about 15 degrees and an altitude of about 900 feet. When it had been firing for about eight seconds, the fins were torn from the rocket. It continued flight, yawing considerably. A few seconds after this, the propellant ran out and the rocket continued flight out of sight," **(Ref. 145).**

The launch crew, consisting of Russell Sessing, author James, Bob Clark, and Bud Hill, spent hours searching the dry lake bed near Barstow, California, but were not able to find the rocket. For many years the cast-off fins decorated the RRI office

Much valuable experience for future asphalt-perchlorate rocket motor development was obtained during the remainder of summer 1949 by author James. Through an invitation from Dan Kimball, President of Aerojet, author James obtained a summer job working, along the along the entire JATO (l4 AS-l000) assembly line.

Further RRI motor development and flight tests had to be suspended for the duration of the Korean War, which began in the summer of 1950. This conflict drafted a number of Institute members into the U.S. Army, including author James. By very fortunate circumstances, he was transferred from the Army Chemical Center, Edgewood, Maryland, to Redstone Arsenal, Huntsville, Alabama, in September; 1951and began his duties as Assistant Technical Editor and Engineering Liaison for Dr. Wernher von Braun, technical director the U.S. Army Ordnance Guided Missile Development Group. At that time Dr, von Braun was directing the development of the Redstone missile. On March 22, 1952, ***Colliers*** published the first of a series of articles, “Man Will Conquer Space Soon,” in which Dr.von Braun had collaborated with his associates during his few spare moments **(Ref 146)**. The following evening, the RRI, in collaboration with the Huntsville Section of the American Rocket Society, held a special public meeting to promote Dr. von Braun’s concepts **(Refs. 147-9)**. Subsequently, nine years later, on May 5, 1961, a modified Redstone launched Astronaut Alan Shepard on the first U.S. sub-orbital flight.

VI. THE SPARK ENGINEERING TRAINING PROGRAM AND RESUMPTION OF ASPHALT-PERCHLORATE ROCKET MOTOR RESEARCH

In 1956, the Sacramento area was in the midst of an industrial rocket expansion program with the attendant large numbers of engineers, from non-aerospace fields, in need of basic rocket design and fabrication experience. The Rocket Research Institute, with the cooperation of the Aerojet Liquid Rocket Company, began, in Sacramento, California, the SPARK (Special Project Altitude Rocket Knowledge) engineering training program.

The SPARK training program was planned to give engineers, laymen, and students a practical working knowledge of rocket propulsion and related sciences by the construction of a two-stage Intermediate Altitude Sounding Rocket for the International Geophysical Year, 1957-1958. The SPARK, in addition to instruments, would also carry special IGY commemorative covers to help raise funds for further RRI research. **(Refs, 150-1).**

The two rockets planned for the SPARK I system were to be a 400-lb thrust, 74 second duration, liquid oxygen-alcohol sustainer rocket and a 10,000-lb thrust, 1 second duration booster rocket using the GALCIT 61-C propellant in a shell and rod configuration **(Refs.152-6).** Over 50 engineers from the Aerojet Liquid and Solid Rocket plants, as well as the Douglas Aircraft facility, participated on a voluntary spare-time basis in this experimental RRI program.

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In order to acquaint the new RRI participants with the properties of asphalt based propellants directed toward the 10,000-lb thrust SPARK booster, several of Russell Sessing’-s motors were brought to Sacramento from RRI headquarters in 1956.

On November 11, 1956, two of these units, nicknamed TARBABIES I and II by the test crew, were statically fired at the test site at the RRI test site located on George Brereton's ranch in Elk Grove, California. “Due to a change in propellant geometry caused by too thick an asphalt liner, TARBABY II did not attain sufficient chamber pressure for designed operation and fired "like a weed-burner" for several minutes at no detectable thrust TARBABY I earned the restricted rocket honors of the day with a beautiful 9.5 second duration, 95-lb thrust firing.”**(Ref.157)**

The following weekend, November 18, 1956, RRI members, elated by the static firing success of TARBABY I, drove to the Carson City, Nevada, Flight Range and prepared to launch TARBABY I boosted by a 5-foot long 2-1/2-inch diameter standard Micrograin rocket. By late in the afternoon, the two-stage combination was ready for launching. However, the weather had become very cold by the time that TARBABY I and its booster could be launched. Upon ignition, TARBABY I exploded violently, damaging the launching rack **(Ref.158).** Its booster, also ignited, leaving the rack and landed several thousand feet away. Institute testing safety precautions of distance or adequate cover prevented any casualties from the flying fragments. TARBABY's explosion, following its successful test the preceding week, was attributed the low ambient temperature or to too large an ignition charge, The film of this explosion was subsequently featured in RRI safety training films to demonstrate the explosive violence of even a relatively small rocket motor.

The professional responsibilities of Rocket Research Institute members employed at the Aerojet Liquid Rocket Plant, to develop the alternate liquid rocket engines for the stage-and one-half Atlas ballistic missile and the liquid rocket engines for the two-stage Titan, demanded far more time than the anticipated 8 or 9-hour days, which had been assumed when the SPARK spare-time training program was conceived in early 1956.

SPARK I liquid rocket component tests were underway, but well behind schedule. As an example, the first full system static test firing was not conducted until June 9, 1957. Neither volunteer time nor funding remained to develop the 6,000-lb thrust asphalt-perchlorate booster by July 1, 1957, the start of IGY. An alternative plan was initiated to launch the SPARK later during the International Geophysical Year (IGY) by using a cluster of six of the standard 12-foot long, 3-inch diameter, RRI Micrograin cargo rockets, which would produce a total impulse of 8,400 lb.

In the meantime, to raise funds it was decided to conduct RRI Rocketpost 57/4 using five of the six Micrograin motors being constructed for the Spark booster to commemorate the start of the IGY. The hope remained that the funds raised through the letters presented to stamp collectors, as the RRI’s tokens of gratitude for their financial donations to the RRI, would help continue financing the SPARK I program so that it would still be possible to launch either of the SPARK sounding rockets before the end of the eighteen-month IGY.

Thus, in what was, at the time, the world’s largest transport of rocket mail, 5,000 covers were flown by the five RRI Rocketpost 4 Micrograin cargo rockets a distance of one and one quarter miles from Douglas County, Nevada, to Topaz, Mono County, California, on Monday, July 1, 1957, the start of the International Geophysical Year. All five rockets functioned perfectly and landed within a 500-foot circle on the California side of the border at the end of their flight **(Ref. 159-161).**

With the funds from the IGY rocket mail endeavor, research continued on the SPARK program.

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On December 1, 1957, 18 months of effort resulted in the successful static test of the simple 400-lb/1779-N thrust liquid oxygen/alcohol thrust chamber capable of being used as a training supplement in college level aerospace engineering programs **(Ref. 162-3).** The SPARK I rocket was conceived by the late Edward Neu, Manager of Thrust Chamber Design at Aerojet, who formerly occupied a similar position at Reaction Motors. The project's development groups, airframe, facilities, project coordination, liquid propulsion systems, and solid propulsion systems were guided by Dr. E.R. Mertz, Frank C. Valls, Gunther F. Peltz, Walter S. Cunnan, John W Salter, Gale Stromberg, Lloyd E. Finden, and Peter R. Burgin.

However, two months earlier, on October 4, 1957, the Space Age began with the launching of Sputnik, the first artificial satellite by the then U.S.S.R. Suddenly, newspapers and magazines were publishing accounts of how great numbers of students and teachers, nourished by the

excitement and controversy accompanying this event, were trying to develop their own rockets propulsion systems without adequate supervision or facilities. In one case a teacher was killed **(Refs 164-5)**. and affected all aspects of rocketry developments including the joint RRI/Aerojet “hands-on” SPARK engineering program,

This new rocket safety educator and student challenge that the RRI faced necessitated suspension of the SPARK program and redirected the RRI towards applying its years of rocket safety experience to develop rocket safety education programs for teachers, high school students, and educator activities such as rocket safety workshops, television programs, seminars, field trips, and model rocket launchings at the RRI Perkins Rocket Safety Text Center (PRSTC). **(Refs 166-172)**.

By December 1957, the Institute had established the National Rocket Safety Registry program. The initiation of the NRSR service was a logical evolution of the Institute's preceding 14 years of safety and educational training device and program development. The Aerojet-General Liquid Rocket Plant provided great assistance and support in the first decades of the NRSR program. Few in the aerospace industry had as great an understanding of the need among young people and educators for such experiential activities **(Refs. 173 -175)**.

The principal safety objective of the NRSR program is the discouragement of individual rocket propulsion experiments by students working by themselves and the encouragement, through professionally supervision, along with proper facilities and safety procedures, to develop better experimental flight vehicles and payload experiments than they could have done by working alone.

The NRSR youth guidance program continued to grow grew in scope, particularly with the formation of two student "pilot groups," the Sacramento Rocketeers and author Piper's Neptune Rocket and Space Society.

By 1962, research increased on the restricted burning asphalt-perchlorate rocket program primarily because of the enthusiastic support of the RRI supervised student "pilot groups." As these students approached college age, they were looking forward to "engineering projects" they could apply in an extracurricular manner to their college classes. Fortunately, as earlier RRI research has shown, the GALCIT/JPL textbook, *Jet Propulsion*, that author James had obtained at the Caltech bookstore in 1946 certainly presented such engineering information.

VII- DEVELOPMENT OF THE SR AND BR FAMILY OF ASPHALT-PERCHLORATE RRI ROCKET MOTORS

The first project under this reactivated initiative was by Larry Ready, author Piper, and RRI supervisors, Bob Woolf and author James along with several other high school seniors and college

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students Dennis Scharosch and William Ball designed and constructed a pilot scale mixer for this propellant, which served as the prototype for other units used at the Perkins Rocket Safety Test Center (PRSTC) and other Institute facilities.

To avoid the problem exhibited in 1956 of precisely controlling the thickness of the inhibitor thickness on the outside of the propellant grain to the degree necessary to achieve reliable combustion, .it was found that by going to a five-inch diameter motor (that had almost three times the surface area) and by maintaining the same degree of inhibitor thickness control, the liner thickness problem went away.

After examining the data from the first successful static test, which yielded an almost “flat” thrust-time profile, it was clearly demonstrated that this propellant/motor combination would produce the types of results that RRI workshop coordinators and educators were seeking. The motor actually performed the way the *Jet Propulsion* handbook of 1946 said it would. After clearing this major

hurtle the entire program too on a whole new perspective.

VII.a. - THE SR-1 ROCKET MOTOR

The five-inch diameter SR-1 (Sustainer Rocket) “Tarbaby” rocket motor utilized a case-bonded restricted burning propellant grain of GALCIT 61-C. It produced 375 pounds of thrust for 11.5 seconds. The first 5-in diameter units were constructed of commercial steel tubing. Fortunately, about that time, another Sacramento Rocketeer member, Peter Guerin, discovered a large supply of empty military 5-in diameter HVAR rocket motor chambers at a Turlock, California war surplus store. The owner of this store was doing a landslide business selling these cases to local farmers and ranchers for fence posts, well casings, irrigation piping, and dozens of other agricultural and industrial applications.

The RRI research team quickly determined that these 5-inch High Velocity Aircraft Rockets could be cut into two equal pieces 24 inches in length. This was also the length of the newly developed SR-1. The RRI was able to negotiate several large purchases of these units; some for the low price of $3.00 each. A lasting supply has been maintained for many years with no immediate likelihood of depleting the supplies. This allowed for the implementation of a long-range program of over 20 years.

The SR-1 was fitted with a nozzle made from a large bar of copper. Once again, the 1946 *Jet Propulsion* text provided the necessary design parameters. The unit developed was an unqualified success. It produced 375-lb thrust for a duration of 11.5 seconds.

Larry Ready and author Piper decided to evaluate less expensive nozzle materials for this rocket motor. As part of author Piper's Engineering Materials class, he was given permission to use the college materials lab to make metallurgical tests, etc. However, since the school had no facilities for static testing rockets, the remainder of the project was conducted at the Institute's PRSTC site. near Sacramento, California. After tests of several materials, it was found that a steel nozzle with a graphite insert was best from both the standpoint of cost and performance. School facilities were used to microscopically examine the extent of nozzle erosion for each firing.

The design of the SR-1 rocket motor and flight vehicles was based on the results of 20 static tests. The basic rocket motor went through numerous design changes, from the time of its inception in 1962 through the last flight in 1985. Basic parameters are presented in Table 1.

For the static tests at the RRI's PRSTC site, a special concrete cell was built to test the -motors in an

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aft end up test configuration. A RRI built bending beam type load cell and Bourns pressure transducer were used to measure

thrust and chamber pressure. Data was collected and recorded on a Brush Instruments two-channel oscillograph. (a dinosaur by today's standards, but almost state-of-the-art at the time). Most of the testing effort for design verification purposes took place between

1962 and 1968, but continued from time-to-time into the mid 1970s. The results of these static tests, summarized in Table 1, were used to validate ballistic data obtained from the unclassified literature. These results were incorporated into yet another series of design iterations, which ultimately resulted in motor designs that were increasingly flight-worthy. **(Ref.176)**

It was determined after a number of initial static firings that the SR-1 operated most reliably in the chamber pressure regime between 2,300 to 2,700 psi. With the diameter of the propellant grain (not including the inhibitor/liner) established at 4.50 inches, this yielded approximately 15.89 square inches of burn surface. The design Kn ratio selected for the SR-1 was 180:1, which corresponded to a chamber pressure of 2,500 psi and a propellant burn rate of 1.85 in/sec. The Kn ratio is a measure

of a propellant geometry's sensitivity to changes in burning area as a function of nozzle throat area. Small changes in Kn ratio can cause large excursions in chamber pressure. The end burning grain offered the most conservative approach to neutral burning possible. The nozzle (based on the Kn ratio of 180:1) had a throat diameter of 0.335 inches. It utilized the usual 15-degree divergence angle and employed a full expansion ratio of 18.0. This yielded an optimal nozzle thrust coefficient of 1.70. Thus, for a 21.5-inch long grain the burn time was approximately 11.5 seconds. This would vary somewhat as a function of ambient temperature.

The design goal of 2,500 psi. was demonstrated to be a good choice. The design of the propellant grain was extremely straightforward. The grain for the SR-1 burned on one end only. This type of grain was selected for two very good reasons: First, because it yielded the optimal loading fraction in terms of the amount of propellant for the existing chamber volume, and secondly, because no tooling was required to pour the propellant grain, as would be the case if a cored type of perforation were utilized. Since the SR-1 had a low thrust to weight ratio and would be subject to drag and gravity losses over a sustained period of time, the trajectory of the rocket could not be calculated using the integrated equations of projectile motion.

So, with the aid of the computer programming instructor at Diablo Valley College, California, author Piper was able, after one summer session of working on the trajectory problem, to develop an iterative computer program for the IBM 1401 (remember this is was in 1966). The program enabled the calculation of the trajectory of any missile in one-dimensional vertical flight (e.g., sounding rockets). It included such variables as changing drag coefficients as functions of velocity, changes in atmospheric density as a function of altitude, changes in gravity with regard to earth coordinates, etc. This project resulted in an A grade for this special projects course.

After conducting ten static tests, several flight vehicles were built. It was quickly discovered that the Tarbaby's thrust-to-weight ratio was such that either a very long tower or a booster would be needed to attain sufficient initial velocity to ensure stable flight. Unfortunately no such booster existed, for this reason there was a period of about a year and one half where the Tarbaby rocket languished in storage until a reliable booster could be built.

VII.b. –The BR-1 Rocket Motor

The success of author Piper's computer program opened up a door to the design of the BR-1, a booster for the SR-1. Again, permission was granted by the college to use 50 hours of computer time to aid in the propellant grain design of the BR-1 booster. The booster, which was to be approximately the same size as the SR-1 restricted burning rocket, was supposed to produce about

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8,000-lb thrust for a duration of 0.4-sec. John Billheimer, of the Aerojet Solid Rocket Plant, commented on some of the early proposed grain designs of author Piper. A star shaped mandrel was constructed and a suitable loading method was developed. Three motors were statically tested. Results at the PRSTC indicated that the computer program was not as accurate as expected. However, if it were not for the computer, it would have been difficult to design this rocket motor at

all. After about a year of development and testing, a suitable booster rocket called the BR-1 (BR standing for Booster Rocket) was ready to fly. Five flights were conducted at Smoke Creek before

an attempt was made to integrate the Tarbaby into a multi-stage vehicle.

The BR-1 rocket by itself was capable of lofting a 20-pound payload to over 25,000 feet, and did so on all but one of the first five flights. Unlike the SR-1, the BR-1 motor utilized an internally burning eight-point star port configuration. This allowed for the entire 22.2-pound charge of propellant to be completely consumed in less than a second. The BR1 produced nearly 7560

pounds of thrust and had a total impulse of approximately 4158-lb-sec. Its parameters are shown in Table I. Unlike the SR-1, the BR-1 motor utilized an internally burning 8-pointed star port configuration. This allowed for the entire 22.2-lb charge of propellant to be completely consumed in less than a second. **(Ref. 177-180).**

Finally, it was possible to mate a SR-1 with its BR-1 booster to come up with a usable two-stage sounding rocket. A special coupler section was designed and the two-stage rocket became a reality. After four years of work, the reward was reaped. At 2:30 pm PDT on Monday, September 11, l967, the 140-lb BRX-1 vehicle was loaded onto the launcher set at a 75-degree angle. AT t-3 seconds, the smoke flares were ignited and the second-stage ignition system was activated. Upon command, the fire switch was pressed at the flight control center 2500 feet away and the flight was underway.

After a 1-second pressure buildup in the booster, the rocket left the launcher with a tremendous roar. At T +05 seconds, the booster had expended itself. Both stages coasted together for 2 seconds. Then, at approximately 2,000 feet, separation occurred and two distinct smoke trails could be seen, one from the booster dropping away and the other from the sustainer firing.

After the sustainer 11.5-second burning duration (at t +14 seconds), the altitude was estimated at 12,500 feet and the angle of flight at about 30 degrees. The two sighting stations were located on a 15,000-foot baseline. Station 1 reported a peak altitude of 15,000 feet and Station 2 reported 13,000 feet. At T +47 seconds, the electronic timer ejected the parachute. This was finally confirmed by finding, in 1968, the parachute canister approximately 36,000 feet from the launch point. The booster stage was located 9,500 feet down range at a depth of 12 feet. The flight, at the RRI Smoke Desert Flight Test Center, north of Reno, Nevada, was a complete success and was the start of a student payload-launching program that extended to 1985. Associated with author Piper in this historic project were Paul DeBak, Bob Garbutt, Reg Jensen, Dan Mika, Steve Post, and Bob Woolf **Refs. 181-182)**.

During the Student Experimental Rocketry Program and RRI development activities, the SR-1 rocket motor was integrated into no less than 5 different flight configurations: usually as an upper stage in a multi-stage vehicle. Over the years, 18 SR-1s were launched atop the BR-1 booster.

Typically these rockets, when launched vertically, would carry a 25 lb. payload to around 50,000 ft.

Early flight configurations utilized the BR-1 motor as a booster. Then came the BR-2. Finally, during the late 70s and early 80s the

BR-3 was utilized as the booster of choice.

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The BR-1s accelerate so rapidly that only a very minimal launcher was required. Richard Bennett, Past- President of the RRI supported Sacramento Rocketeers, independently devised a launcher dubbed the “zero-length launcher,” which essentially restrained the rocket for only an inch or so before it entered powered flight. This launcher was so successful that it was adopted for use in all future applications of this type and class of rocket. It could even be used for multi-stage applications. It certainly simplified the logistics of transporting launchers to the desert, replacing the large cumbersome rail type launchers used in years past with a small (almost disposable)

launcher that could be placed in the trunk of an ordinary passenger car **(Ref. 183)**.

A significant potential contribution to future RRI asphalt-perchlorate rocket technology came in

1976 when RRI member Cliff Adams developed a cartridge reloadable motor based on the BR-1. Cliff, then on active duty in the U.S. Air Force at Mather AFB, found that he could make a thin sheet metal sleeve, apply inhibitor to the inside portion of the sleeve while it was constrained in a steel mold with an inside diameter approximately 0.030 inch smaller than the inside diameter of the BR-1. At the time there was no pressing reason for the RRI to pursue the reload program. There was no problem transporting loaded rocket motors and, at $3 to $5 apiece for the motor cases, they could essentially be considered as throwaways. The reloads also added an additional layer of complexity to the construction of the final rocket vehicle which, for some, was already complicated enough **(Ref. 184)**.

The successful BR-1/SR-1 combination enabled altitudes of over 50,000 feet to be reached. Nine of these two stage vehicles were built and flown, when one of the RRI staff suggested that an even larger booster, utilizing the entire 48-inch long HVAR motor case, be developed. This would allow a three-stage vehicle to be constructed. Two motors, the BR-2 and BR-3, evolved from this effort. Both utilized an internal burning six-point star perforation in the propellant grain and burned 40 pounds of GALCIT propellant in just under a second.

VII.c. - The BR-2 Rocket Motor

The BR-2 rocket motor was the third in a series of experimental rocket motors built by the Rocket

Research Institute to utilize asphalt/perchlorate propellants under the direction of author Piper. Before its appearance, the BR-1 and SR-1 rocket motors were the only non-commercial production type rocket motors available for the RRI's Experimental Rocketry Program.

From 1976 to 1982, a total of 10 BR-2 motors were built by RRI, and used as booster motors for multi-stage vehicles. The BR-2s were launched exclusively at the RRI's Smoke Creek Desert Flight Range. An additional 4 motors were static tested at the RRI's PRSTC site. Eventually the BR-2 was replaced by another motor called the BR-3, which had the same dimensions, slightly lower performance, and could be built with considerably less effort. Unlike the BR-2, it could also be easily adapted to single stage applications. This explains why so few BR-2s were ever made.

The BR-2 had a total impulse of around 7,400 lb.-sec. and a nominal peak thrust of 16,600 lbs, as noted in Table I. In addition to being a much larger booster (with nearly one-and-three-quarter

times the total impulse of the BR-1) it radically reduced the amount of effort required to make a booster motor. The BR-1, which as previously stated, was made from only the first 32-1/2 inches of the HVAR case, required extensive machining and welding.

The BR-2 utilized the entire 48 inches of the HVAR case and required machining only on the nozzle. It utilized an internal burning 6-pointed star perforation in the propellant grain, and burned almost 40 lbs. of GALCIT propellant in just under 3/4 second. The BR-2 also employed a large full expansion nozzle, made from a hand-lay-up of glass/epoxy. By attaining maximum thrust

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coefficient from the nozzle, a booster of optimal performance was obtained. The SR-1/BR-2 multi-stage vehicle combinations were capable of reaching altitudes in excess of 80,000 ft.

Unlike the 8-pointed star grain used in the BR-1, (which was regressive burning) the 6-pointed star grain selected for use in the BR-2 was progressive burning. As a starting point an average design chamber pressure of 2,000 psi was selected. Because of the burn trend profile, it was known that the actual chamber pressure would have to start at a value somewhere below this amount, and exceed it by an almost equal proportion. A nozzle area of 3.8 square inches (based on a Kn ratio of 170:1) was computed. Additionally, it was also known well in advance, that this was going to be an iterative process (with considerably more than one iteration). The mandrel design would supply the

required burn perimeter, with only a small variance over the duration of the burn.

The geometry of the mandrel, and the resulting perimeter trace indicated that the initial perimeter of the burn surface was 13.95 inches (or an initial surface area of 627 square inches). Needless to say, a number of computer programs were run, and all the factors, such as erosive burning, resonance, stress concentration, and combustion termination sliverage were evaluated, prior to arriving at a final mandrel design. In the final analysis, only testing would tell for sure.

Surprisingly enough, static testing verified that the grain design tracked quite closely with the computer model through the initial portion of the burn. However, the peak chamber pressure was significantly lower than expected (2,650 psi. as opposed to 3,500). In an unexpected turn of events, the nozzle throat had eroded slightly (0.025-inch). This increase in throat diameter dropped the Kn ratio to around 182. This actually turned out to be a positive attribute. This erosion was somewhat puzzling, as the SR-1 motor nozzle, which also used a graphite nozzle insert, experienced no such erosion of the nozzle throat until after 18 seconds of exposure. It was surmised that this could be accounted for as part of a heat flux/mass flow rate phenomenon.

Although the final grain geometry selected was by no means the most optimal in terms of volumetric loading, it represented a reasonable compromise between the complexity of fabricating a suitable mandrel and attempting to select a geometry that would yield a burn area/time profile that was still progressive burning, but as near-to-neutral burning as possible.

The expansion ratio for the BR-2 nozzle is approximately 17.0 to 1 for the optimal (fully expanded, and at an arbitrary chamber pressure of 2,300 psi.). In theory, this nozzle has a thrust coefficient of around 1.68. **(Ref. 185)**

This meant that the nozzle exit diameter would have to be 9.00 inches. Some discussion regarding nozzle erosion was entertained, but the general consensus was, that since the BR-2 was pretty much a one-way ride, there was no point in correcting a phenomenon that actually acted in our favor.

A RRI record of sorts was set in 1979, when a three stage rocket, which utilized a BR-2 motor as a first stage, a BR-1 motor for the second stage, and a SR-1 sustainer motor for the third stage

(carrying a 25 lb. payload) was flown and optically tracked to an altitude in excess of 110,000 ft. This was the only such rocket of its type to be built by RRI, as most student payloads operated at lower altitudes **(Ref. 186).**

VII.d. – The BR-3 Rocket Motor

The BR-3 rocket motor was the fourth and final design, directed by author Piper, in a series of experimental rocket motors built by the Rocket Research Institute to utilize asphalt/perchlorate propellants. Two other motors, the SR-1 and the BR-1 had been in use for 8 years prior to its

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introduction. The third motor, the BR-2, had been in use for almost 2 years.

The BR-3, which had essentially the same dimensions as the BR-2, had slightly lower performance but could be built with considerably less effort. Unlike the BR-2, it could also be easily adapted to single stage applications.

The design of the BR-3, and parameters presented in Table 1 are based mostly on static test and flight data obtained from the BR-2, which was, for all intents and purposes, an almost exact clone of the BR-3.

Even during the early days of the BR-2 program it was known that the existing nozzle for the HVAR motor could be modified and used, if one was willing to accept a substantial loss in performance. By the second year of working with the Estacada, Oregon students, it had evolved into an idea whose time had come (see Section VIII). After all, the main purpose of these motors was for teaching propulsion principles, not the optimization of performance. This fact that somehow became a little convoluted during the BR-2 development. By eliminating the rupture disk assembly on the HVAR nozzle, and enlarging the hole left by its removal, and possibly enlarging each of the 8 sub-nozzles a little, it was possible to make a nozzle for the BR-3 with very little effort. This was not without incurring an approximate 15 percent loss in performance. Considering cost and time constraints imposed by having to work within the boundaries of the average school year, it was well worth the compromise.

Basically, what was envisioned was a BR-2 motor with a nozzle that required little or no effort to make. In other words, utilize the basic HVAR motor case, and bulkhead (head-cap) and to do so without any cutting, machining, or welding (except for the nozzle). As with the BR-2, the dimensions of the combustion chamber were essentially dictated by the economy of being able to use the entire 48-inch length of the HVAR (unlike the BR-1 which only used the first 32.5 inches, and had a welded bulkhead).

In order to accomplish the direct conversion of the HVAR into a BR-3, the HVAR nozzle throat area had to be increased from the nominal 2.46 square inches, to somewhere around 3.6 square inches. By removing the central rupture disk assembly, and boring the resulting hole left by its removal to a diameter of 1.20 inches, it was possible to achieve the proper conditions needed for stable combustion of the propellant. This modification had the effect of causing the resulting exhaust flow to be more under-expanded than ever, resulting in a thrust coefficient even lower than that demonstrated by the nozzle for the BR-1. However, the good news was that it was not necessary to enlarge the diameter of 8 sub-nozzles, as originally thought.

The first, last, and only static test of static test of the BR-3 was conducted at the RRI PRSTC Site on the same stand used for testing the BR-2. The stand was equipped with a 25,000 lb Statham Instruments load cell and used the same control room and instrumentation used for all other testing at the site.

Ignition of the propellant grain was achieved, and combustion was stable. An igniter identical to that used in the BR-2 motor was used. The only problem experienced, was that the pressure

transducer failed, as the chamber pressure must have been greater than anticipated, or the transducer was defective. The transducer was only rated for a maximum pressure of 2,500 psi. Other than being slightly lower in places you could almost take the BR-3 pressure trace and lay it over the BR-2 trace **(Ref. 187)**.

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The BR-3 also exhibited a nominal variance from motor to motor, (usually attributed to temperature effects, or tolerance endemic to the grain trimming process), but this has never been a problem. The data in Table 1 is representative of the typical BR-3 rocket motor when fired at an ambient temperature of 70 Deg. F.

Richard Bennett is also credited for developing another motor very similar to the BR-3. This motor also utilized the entire HVAR case and existing nozzle and was based on an ingenuous concept known as the “moon burner” propellant grain. The moon burner propellant grain, which used a tear drop-shaped off line-of-center port, was considerably easier to cast than the six pointed star and

yielded a thrust/time profile that’s was much less stressful on payloads **(Ref .188)**. This was a truly remarkable achievement, as the moon burner grain had an almost flat Kn ratio during its entire burn. (Kn ratio is defined as the ratio between the propellant burning surface and the nozzle throat’s cross-sectional area,) Those who are aware of the ballistic properties of GALCIT

propellants know that they possess a very high burn rate exponent. This is to say that small changes in the Kn ratio can cause substantial changes in the chamber pressure, which, in turn, can cause tremendous changes in propellant burn rate. Since these propellants must out of necessity burn at pressures above 1,800 psi, either of these anomalies can become a real problem.

In addition to being a much larger booster, with nearly twice the total impulse of the BR-1, it radically reduced the amount of effort required to make a booster motor. The BR-1, which was made from only the first 32.5 inches of the HVAR case, required extensive machining and welding. Total impulse produced by this motor was around 6300 lb-sec. The major difference between the BR-2 and BR-3 is that the BR-2 had a large “full expansion nozzle” made from a hand lay-up of glass/epoxy, and the BR-3 utilized the nozzle that originally came with the HVARs. As it turned out the existing HVAR nozzle had a thrust coefficient only 9% less than optimum for the GALCIT propellant. Considering the amount of work involved in fabricating the full expansion nozzle, it was decided to discontinue its use in favor of the HVAR nozzle, which was another Rick Bennett innovation.

During the Student Experimental Rocketry Program and RRI development activities, the BR-3 rocket motor was integrated into 3 different flight configurations: usually as booster in a multi-stage vehicle. Earliest flight configurations utilized the BR-3 motor as single stage vehicle. During the early 80s the BR-3 was utilized as the booster of choice, replacing the more complex, more expensive BR-2.

The BR-3 rocket motor and related flight vehicles, like all other vehicles used in the RRI student experimental Rocket Program, were supplied in kit form, and was intended to be assembled and integrated with other flight components at the launch site. The BR-3 kit consisted of the motor, the nozzle assembly, fins, launch lugs, staging adapter, and when used as a motor in single stage vehicles, a payload section. Since the BR-3 was usually used as a booster stage, the launch lugs and staging adapter section

were usually considered to be part of the booster rocket. When the BR-3 was utilized as a single stage rocket, the fins were usually machined from 3/8 inch thick aluminum

stock, with leading and trailing fin surfaces machined on a milling machine or planer. The fins were then bolted to the nozzle assembly from the inside with high-strength hex-socket cap screws. The dimensions of the fins varied from vehicle to vehicle depending on size, mass properties, and the

amount of surface area required achieving initial stability.

VIII – SUCCESS OF THE BR MOTORS FOR STUDENT PAYLOAD LAUNCHES

The net result of all of these innovative developments was a family of rocket motors that could be

assembled in much the same way as a large “model rocket” Experimenters, at RRI launch sites,

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could use these motors to launch payloads without having to worry about the complexities and safety concerns normally associated with the development of rocket hardware and propellant manufacturing, thereby allowing them to concentrate their efforts on payloads and recovery systems.

In other words, the experimenter would be furnished with an inert motor for conducting airframe integration and other mass properties evaluation on their vehicle prior to launch. At a prearranged date they would simply show up at the launch site where an RRI furnished rocket motor, having identical motor/payload interfaces would be waiting for them. The experimenter would then simply attach his or her payload to the RRI supplied motor and be ready to launch with a minimum amount of preparation.

Through the dedication of the RRI Western Operations staff, under the direction of author Piper, over 200 BR series solid propellant rocket motors have been launched for educational programs, to altitudes in excess of 25,000 feet, under RRI supervision, at the RRI's Smoke Creek Flight Range and other FAA approved launch sites, with an over 90 percent reliability.

In 1984, the RRI lost the use of the PRSTC, its manufacturing and test site. Several years' prior, the RRI's chief patron and benefactor had passed away. It appeared that his heirs would be forced to sell the land upon which the test site was located to developers. Not wanting to be caught unprepared, several members of the RRI had already purchased property for a new site in another northern California county, and were just waiting for the inevitable to happen. For a brief period of time, the Student Rocket Motor Program at the PRSTC was suspended while the RRI started moving equipment and whatever facilities it could to the new undeveloped site.

However this RRI educational program was able to continue by transferring the tooling and motor hardware to a supervised program, established by the RRI in Estacada, Oregon. This was as a result of Michael Donohoe of NASA’s Western Operations Office contacting authors James and Piper. Through the technical guidance of author Piper, Dr. Leroy Key (then) Superintendent Of Schools established a high school program utilizing the RRI developed asphalt-perchlorate motors.

When Dr. Key moved to White Fish, Montana, he took the program with him. Dr. Key's excellent contribution to “hands-on” educational rocket programs earned him the prestigious 1982 National Science Foundation’s Ohaus Corporation-sponsored Educator of the Year Award. After accepting a position as Superintendent of Schools in Whitefish, Montana the program continued under his expert tutelage (and RRI assistance), for several more years. Almost a hundred students built and launched several dozen of these Asphalt-Perchlorate powered rockets at Nevada’s Smoke Creek Desert and at another Federal Aviation Administration (FAA) approved launch site near the town of Malta, Montana **(Refs 189-194).**

Unfortunately, after just a few short successful years the program at Whitefish suffered a fate similar to that of many experimental educational experiential program (school district politics) and Dr. Key had to stop this space-related experiential educational activity.

IX – BR MOTORS AND RRI EMERGENCY CARGO DELIVERY RESEARCH

As noted early in this paper, one of the long term RRI research objectives has been the development through rocketpost experiments of rocket systems for high speed delivery of medical and or other emergency supplies during weather conditions so severe that delivery by other means is not possible.

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That rocket propelled vehicles can operate under extreme weather conditions was dramatically demonstrated on February 25, 1960, during a severe snow storm on the opening day of the

VIII Olympic Winter Games in Squaw Valley, California. In a nearby valley, during weather so severe that, then, Vice-President Richard Nixon could not be flown into Squaw Valley by helicopter for the opening ceremonies, the RRI successfully launched during a blinding snowstorm two Micrograin cargo rockets, that successfully carried 2,100 covers over an one and one-half mile range, to honor the VIII Olympic Winter Games, **(Ref. 195).**

The unexpected snowstorm on the opening day of the Olympics slowed down the preparation for launching but did not affect the performance of the rockets. Both Olympia I and Olympia II made successful flights and impacted on a snow-covered hillside in Sierra County. Brilliant fluorescent orange “Scotchcal” panels on the triangular, letter-carrying, fins inscribed with the Olympic emblem, aided location of the black rockets against the black and white landscape.

Survival of emergency cargo following rocket impact is a key study. Cargo within fins, such as used above has continued to demonstrate complete survivability at the impact velocities of the RRI Micrograin cargo rockets following their one and one half mile flights through the shock-absorbing crumpling of the 3-inch diameter by 12-foot long propulsion chambers. Now with the availability of the BR family of motors, having total impulses exceeding four times that of the Micrograin cargo rockets, the study of cargo survival from much higher impact velocities has become a research possibility.

Thus, in coordination with the RRI Student Payload Launching Field Trips, the BR family of asphalt-perchlorate rocket motors has been used for RRI Rocketpost experiments

RRIRP-73/36 (May 27, 1973); RRIRP-76/37 (September 5, 1976); RRIRP-81/38 (October 17, 1981), RRIRP-83/40 (May 28, 1983), RRIRP-84/41 (May 27, 1984); and 85/42. (May 11, 1985) **(Ref. 196)**. Ranges of up to 5 miles have been achieved.

However, cargo protection, if parachute mechanisms do not operate successfully, still present many problems be solved through future experiments.

One of the highlights of these experimental rocket mail flights, RRI Rocketpost 76/37, flown at Smoke Creek on September 5, 1976 was that this rocketpost experiment was an officially recognized U.S. Bicentennial Event (No. 20003l-025) in Commemoration of the United States Bicentennial, 1776-1976 **(Ref 197-198).**

In 1983, a California experimental rocketry association known as the Foothill Rocket Team (FORT), associated as a student club with Foothill College, and also as a committee of the Bay Area Chapter of the L-5 Society, planned to develop a standardized flight vehicle for launching large student payloads that would be propelled by RRI-developed BR-3 motors. They approached the RRI to launch their prototype FORT I vehicle during the 1983 Desert rocket field trip.

The BR-3 rocket motor to be used for the launch of their vehicle was made in Montana by the Whitefish School District rocket group. The FORT group's prototype 7-½ inch diameter, 15-foot long FORT I flight vehicle was designed to have the BR-3 motor inserted much in the manner of a

high-power model rocket motsor. The motor was transported to Smoke Creek for integration with the FORT vehicle. As can be imagined, it took a considerable amount of planning and logistics between author Piper and the two groups almost 800 miles distant from one another. The FORT I's long payload section contained an altimeter, a temperature sensor, a humidity sensor, and a 16mm gun camera. In addition there was space for a special rocket cargo capsule designed by RRI staff member Ed Quarterman containing the 200 commemorative items for RRI Rocketpost 83/40,

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honoring the Rocket Research Institute's 40th year **(Ref. 199).**

The FORT I vehicle, with its spectacular BR-3 launch on May 11, 1983, rose to an altitude of approximately three miles. Unfortunately, on the descent trajectory, neither the small drogue chute nor the main parachute deployed as the vehicle spun down from its peak altitude. Ed's rocket cargo container survived impact completely intact. The undamaged covers were cancelled in Reno, Nevada, the following day. Eventually the trustees of Foothill College, fearing potential liability problems with this type of experiential educational activity, "pulled the plug" on the FORT's development of their standard payload launch vehicle.

Two years later, on May 11, 1985, the cooperative RRI/Whitefish student launching campaign, was conducted at an FAA approved launch site near Malta, Montana. A Whitefish produced BR-3 rocket motor, fitted to a student constructed forward section, carried another Ed Quarterman designed rocket cargo capsule, containing the 207 commemorative postal items of RRI Rocketpost 85/42, in a high trajectory, to an impact point five miles away **(Ref. 200).** Thus the RRI has been able to continue its research into emergency cargo delivery systems in the course of conducting a very active student experimental rocketry education programs..

X –PLANS FOR THE FUTURE

Eventually, work began on the newest RRI facility for solid and liquid rocket research, development, static testing, and for rocket motor manufacture, the "Rocket Ranch" (RRTS), in northern California. The Ranch is now up-and-running on a limited basis for activities such as liquid and hybrid rocket engine static testing **(Ref. 201 & 202)** .

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However, while BR motors can be loaded and research-static-testing conducted at the RRTS it is no longer possible for a non-profit volunteer educational organizations such as the Rocket Research Institute to transport any loaded rocket motors to flight ranges. U.S. regulations continue to increase regarding transport of explosive materials. Consequently, it is no longer legally possible to transport large high performance rocket motors to remote launch sites without exorbitant insurance fees **(Refs. 203-206).**

As a result, current Institute research planning is aimed at the long term development of transportable completely inert manufacturing systems for the "at-launch-site" propellant manufacture and rocket motor processing at remote FAA approved locations such as Smoke Creek in order to comply with recent U.S. regulations regarding highway transportation of high-energy loaded rocket motors.

Thus, the Institute continues to remain optimistic that, in the long term, asphalt-based rocket motors will still have the potential into the 21st century for safely and cost-effectively lofting supervised student educational and other experimental payloads.

XI - ACKNOWLEDGEMENTS

The Rocket Research Institute has been extraordinarily fortunate over the past 50 years in the caliber of the individuals who have chosen to devote their free time to Institute research and

education activities. The selfless efforts of hundreds of volunteers have kept alive the concept of motivating and mentoring young people in the pursuit of their careers in engineering and the

sciences by providing experiential ("hands-on") experience in the aerospace sciences through using scientific and engineering knowledge and techniques generally not available in most curricula as well as through individual contact with professionals in each student's personal field of interest.

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In preparing the Institute's portions of this paper on the evolution of asphalt-based solid propellants, authors James and Piper, as the representatives of these RRI volunteers, wish to state how extremely fortunate they consider themselves to be and express their gratitude to be in association with such a network of dedicated volunteers.

Also, over the past 50 years, the RRI experiential programs have been fortunate in receiving encouragement from a number of individuals in the space community. Early among these was Cedric Giles of the American Rocket Society, who in 1944 listed the Glendale Rocket Society in his list of the 31 known rocket societies, when what is now the RRI was an organization of teen

agers **(Ref. 207)** Members of the California Rocket Society generously donated test equipment to our young organization **(Ref. 208)**. As has been noted earlier Drs. Theodore von Karman, Frank Malina, Hue-shen Tsien, and Howard Seifert of the California

Institute of Technology as well as Dan Kimball, President of Aerojet, provided encouragement. Jim Broadston and Jim Benson, o the North American Aerophysics Laboratory Navaho program, were supportive and provided technical advice. During the "early Redstone development years," Konrad Dannenberg, Dr.Kraft Ehricke, and Dr.von Braun, perhaps thinking back to their youthfu experiments in Germany, expressed approved of the RRI's experiential programs **(Refs. 209-210).**. RRI members met Mrs Goddard in 1964 at the Roswell, New Mexico ceremonies honoring her husband Dr. Robert H. Goddard. She graciously assistec in the launching of RRI Rocketpost 64/14 and maintained an interest in Institute activities for many years afterward (Ref. **211).**

In 1968, Frederick C. Durant, III, Assistant Director of the Smithsonian's National Air and Space Museum, briefed Professor Luig Napolitano, President of the International Astronautical Federation, on the RRI's student rocket safety education programs **(Ref 212-213).** Subsequently, Professor Napolitano, realizing the need for international coordination of safe hands-on studen experiential space-related educational activities, asked author James and Lise Blosset of the French Space Agency to form the Safety in Youth Rocket Experiments (SYRE) study group. Among the first members were rocket pioneers, in addition to Frank Malina, were Robert C. Truax and Irene Sanger-Bredt. **(Ref.214)**. Thus the RRI safety concepts begun in 1943 and the CNES student programs, based upon RRI concepts, that began in the early 1960's, now had a role in coordinating student rocket safety programs internationally as the SYRE sessions continued at each International Astronautical Congress, **(Refs. 215).** Then, ir 1993, in Graz, as author James notes in Section V of this paper, the great pleasure he and his associates had in hearing Friedrich Schmiedl, the rocket mail pioneer, compliment the Rocket Research Institute on continuing the rocketpost research he first begar in the late 1920's into high priority emergency cargo delivery by rocket **(Refs. 216-217)**.

We also wish to acknowledge with gratitude the support given over the years to the Institute by the Aerojet-General Corporation's Sacramento Liquid Rocket Plant in supporting the RRI rocket safety and educational endeavors. We particularly wish to thank Joe Lipper and his successor Tom Sprague of Aerojet's Public Relations Department for their belief in and support of the studen educational programs of the Rocket Research Institute that included, among other integrated activities, the Smoke Creek Deser student payload launchings by the BR family of asphalt-based rocket motors **(Ref. 218-219)**.

XII - NOTES AND REFERENCES

Notes and References to: IAA-99-IAA.2.2.04 – 9/3/2006

EVOLUTION OF ASPHALT ROCKET PROPELLANTS FROM WORLD WAR II JPL/AEROJET RESEARCH TO POSTWAR SPIN-OFFS

BY THE ROCKET RESEARCH INSTITUTE

By Charles J. Piper III, George S. James, Frank H. Winter, and John Bluth

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